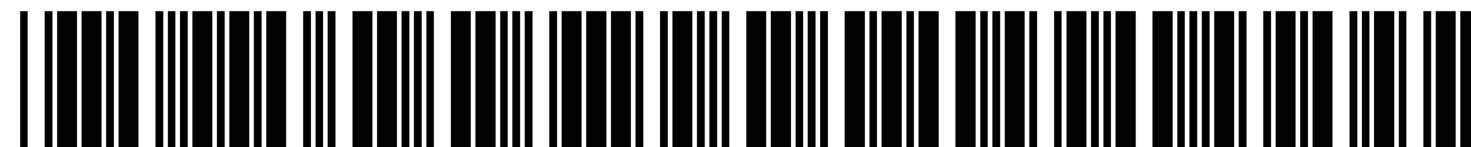

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Parish et al.

(10) **Patent No.: US 7,804,686 B2**
(45) **Date of Patent: Sep. 28, 2010**

(54) **THERMAL CONTROL SYSTEM FOR RACK MOUNTING**

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(63) Continuation of application No. 11/202,885, filed on Aug. 12, 2005, now abandoned.

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(51) **Int. Cl.**
H05K 7/20 (2006.01)
F28D 15/00 (2006.01)

(52) **U.S. Cl.** **361/696**; 361/695; 361/698; 361/699; 361/701; 165/104.33

(58) **Field of Classification Search** 361/699–703, 361/695, 696, 698; 165/80.4–80.5, 104.33
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

773,828	A	11/1904	Titus et al.
2,110,022	A	3/1938	Kliesrath
2,504,308	A	4/1950	Donkle, Jr.
3,014,117	A	12/1961	Madding
3,345,641	A	10/1967	Jennings
3,367,319	A	2/1968	Carter, Jr.
3,608,091	A	9/1971	Olson et al.
3,660,849	A	5/1972	Jonnes et al.
3,736,764	A	6/1973	Chambers et al.
3,738,702	A	6/1973	Jacobs
3,744,053	A	7/1973	Parker et al.
3,862,629	A	1/1975	Rotta

(Continued)

FOREIGN PATENT DOCUMENTS

CH	670 541	6/1989

(Continued)

OTHER PUBLICATIONS

Artikis, T., PCT International Preliminary Report on Patentability as mailed Jul. 29, 2005, (9 pgs.), PCT/US04/023244.

(Continued)

Primary Examiner—Jayprakash N Gandhi
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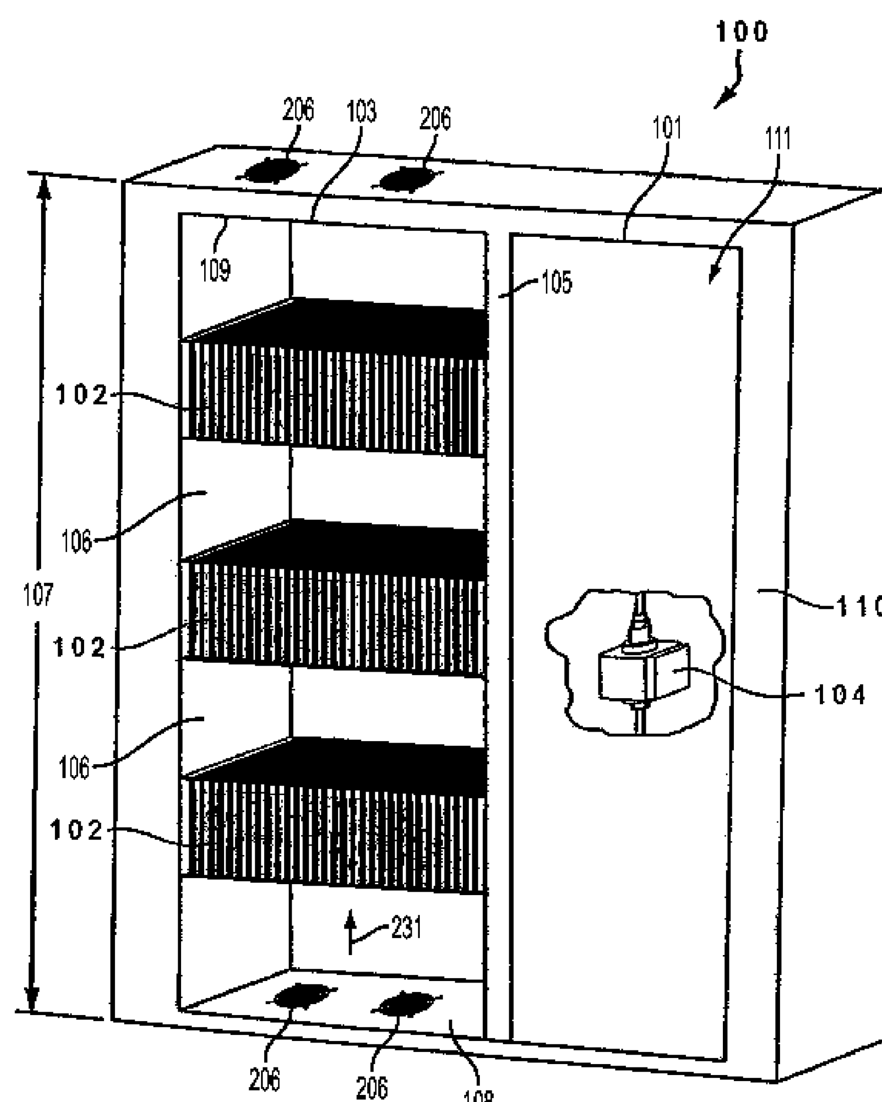
(57) **ABSTRACT**

A thermal control system of a 3U height includes various modules for providing temperature control in a rack environment. The modules may be, for example, a power module, user interface module, various different pump assemblies, various different models of fan assemblies, HTAs, and/or a serial communication interfaces.

10 Claims, 8 Drawing Sheets



U.S. PATENT DOCUMENTS

3,894,213 A 7/1975 Agarwala
4,006,604 A 2/1977 Seff
4,013,069 A 3/1977 Hasty
4,459,822 A 7/1984 Pasternack
4,503,484 A 3/1985 Moxon
4,547,906 A 10/1985 Nishida et al.
4,660,388 A 4/1987 Greene, Jr.
4,821,354 A 4/1989 Little
4,844,072 A 7/1989 French et al.
4,884,304 A 12/1989 Elkins
4,901,200 A 2/1990 Mazura
4,911,231 A 3/1990 Horne et al.
4,962,761 A 10/1990 Golden
4,979,375 A 12/1990 Nathans et al.
4,996,970 A 3/1991 Legare
5,044,364 A 9/1991 Crowther
5,067,040 A 11/1991 Fallik
5,080,089 A 1/1992 Mason et al.
5,092,271 A 3/1992 Kleinsasser
5,097,829 A 3/1992 Quisenberry
5,106,373 A 4/1992 Augustine et al.
5,112,045 A 5/1992 Mason et al.
5,125,238 A 6/1992 Ragan et al.
5,165,127 A 11/1992 Nicholson
5,179,941 A 1/1993 Siemssen et al.
5,184,612 A 2/1993 Augustine
5,186,698 A 2/1993 Mason et al.
5,232,020 A 8/1993 Mason et al.
5,241,951 A 9/1993 Mason et al.
5,243,706 A 9/1993 Frim et al.
5,263,538 A 11/1993 Amidieu et al.
5,285,347 A 2/1994 Fox et al.
D345,082 S 3/1994 Wenzl
D345,609 S 3/1994 Mason et al.
D345,802 S 4/1994 Mason et al.
D345,803 S 4/1994 Mason et al.
5,300,101 A 4/1994 Augustine et al.
5,300,102 A 4/1994 Augustine et al.
5,300,103 A 4/1994 Stempel et al.
5,303,716 A 4/1994 Mason et al.
5,316,250 A 5/1994 Mason et al.
D348,106 S 6/1994 Mason et al.
5,323,847 A 6/1994 Koizumi et al.
5,324,319 A 6/1994 Mason et al.
5,324,320 A 6/1994 Augustine et al.
D348,518 S 7/1994 Mason et al.
5,330,519 A 7/1994 Mason et al.
5,336,250 A 8/1994 Augustine
5,343,579 A 9/1994 Dickerhoff et al.
5,350,417 A 9/1994 Augustine
D351,472 S 10/1994 Mason et al.
5,352,174 A 10/1994 Mason et al.
5,354,117 A 10/1994 Danielson et al.
D352,781 S 11/1994 Mason et al.
5,360,439 A 11/1994 Dickerhoff et al.
5,370,178 A 12/1994 Agonafer et al.
5,371,665 A 12/1994 Quisenberry et al.
5,402,542 A 4/1995 Viard
5,405,370 A 4/1995 Irani
5,405,371 A 4/1995 Augustine et al.
5,411,494 A 5/1995 Rodriguez
5,411,541 A 5/1995 Bell et al.
5,417,720 A 5/1995 Mason
5,440,450 A 8/1995 Lau et al.
5,449,379 A 9/1995 Hadtke
5,507,792 A 4/1996 Mason
5,509,894 A 4/1996 Mason et al.
5,528,485 A 6/1996 Devilbiss et al.
5,561,981 A 10/1996 Quisenberry et al.
5,566,062 A 10/1996 Quisenberry et al.
5,578,022 A 11/1996 Scherson et al.
5,588,954 A 12/1996 Ribando et al.
5,591,200 A 1/1997 Cone et al.
5,648,716 A 7/1997 Devilbiss et al.
D383,547 S 9/1997 Mason et al.
D383,848 S 9/1997 Mason et al.
5,662,695 A 9/1997 Mason et al.
5,672,152 A 9/1997 Mason et al.
5,675,473 A 10/1997 McDunn et al.
5,682,748 A 11/1997 DeVilbiss et al.
5,689,957 A 11/1997 DeVilbiss et al.
5,690,849 A 11/1997 DeVilbiss et al.
5,711,155 A 1/1998 DeVilbiss et al.
5,731,954 A 3/1998 Cheon
5,755,755 A 5/1998 Panyard
5,772,618 A 6/1998 Mason et al.
5,782,780 A 7/1998 Mason et al.
5,807,294 A 9/1998 Cawley et al.
5,827,208 A 10/1998 Mason
5,831,824 A 11/1998 McDunn et al.
5,890,371 A 4/1999 Rajasubramanian et al.
5,901,037 A 5/1999 Hamilton et al.
5,923,533 A 7/1999 Olson
5,989,285 A 11/1999 DeVilbiss et al.
6,055,157 A 4/2000 Bartilson
6,058,010 A 5/2000 Schmidt et al.
6,058,712 A 5/2000 Rajasubramanian et al.
6,080,120 A 6/2000 Sandman et al.
D430,288 S 8/2000 Mason et al.
D430,289 S 8/2000 Mason et al.
6,125,036 A 9/2000 Kang et al.
6,176,869 B1 1/2001 Mason et al.
6,260,890 B1 7/2001 Mason
6,270,481 B1 8/2001 Mason et al.
6,295,819 B1 10/2001 Mathiprakasam et al.
6,305,180 B1 10/2001 Miller et al.
6,319,114 B1 11/2001 Nair et al.
6,462,949 B1 10/2002 Parish, IV et al.
6,551,264 B1 4/2003 Cawley et al.
6,596,016 B1 7/2003 Vreman
6,667,883 B1 12/2003 Solis et al.
6,675,072 B1 1/2004 Kerem
D486,870 S 2/2004 Mason
6,695,823 B1 2/2004 Lina et al.
6,719,713 B2 4/2004 Mason
6,719,728 B2 4/2004 Mason et al.
6,775,137 B2 8/2004 Chu et al.
6,789,024 B1 9/2004 Kochan, Jr. et al.
6,802,823 B2 10/2004 Mason
6,834,712 B2 12/2004 Parish et al.
6,848,498 B2 2/2005 Seki et al.
6,855,158 B2 2/2005 Stolpmann
6,893,414 B2 5/2005 Goble et al.
6,935,409 B1 8/2005 Parish IV et al.
6,936,019 B2 8/2005 Mason
7,066,949 B2 6/2006 Gammons et al.
7,081,128 B2 7/2006 Hart et al.
7,306,568 B2 12/2007 Diana
7,484,552 B2 * 2/2009 Pfahnl 165/80.4
2001/0039439 A1 11/2001 Elkins et al.
2003/0089486 A1 5/2003 Parish et al.
2003/0089487 A1 5/2003 Parish, IV et al.
2003/0127215 A1 7/2003 Parish, IV et al.
2004/0008483 A1 1/2004 Cheon
2004/0030281 A1 2/2004 Goble et al.
2004/0046108 A1 3/2004 Spector
2004/0054307 A1 3/2004 Mason et al.
2004/0068309 A1 4/2004 Edelman
2004/0099407 A1 5/2004 Parish, IV et al.
2004/0193218 A1 9/2004 Butler
2004/0221604 A1 11/2004 Ota et al.
2004/0260231 A1 12/2004 Goble et al.
2005/0006061 A1 1/2005 Quisenberry et al.
2005/0039887 A1 2/2005 Parish et al.

2005/0133214	A1	6/2005	Pfahnl	
2005/0143797	A1	6/2005	Parish et al.	
2005/0256556	A1	11/2005	Schirrmacher et al.	
2005/0274120	A1	12/2005	Quisenberry et al.	
2005/0284615	A1	12/2005	Parish et al.	
2006/0034053	A1	2/2006	Parish et al.	
2006/0058714	A1	3/2006	Rhoades	
2007/0112401	A1	5/2007	Balachandran et al.	
2007/0282249	A1	12/2007	Quisenberry	
2008/0058911	A1 *	3/2008	Parish et al.	607/104
2008/0071330	A1	3/2008	Quisenberry	
2009/0069731	A1 *	3/2009	Parish et al.	601/150

FOREIGN PATENT DOCUMENTS

DE	35 22 127	1/1987
EP	0 489 326	6/1992
SU	689674	10/1979
WO	WO-93/09727	5/1993
WO	WO-00/40186	7/2000

OTHER PUBLICATIONS

Tom Lee, T.Y. et al; “Compact Liquid Cooling System for Small, Moveable Electronic Equipment”, IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Oct. 15, 1992, No. 5, pp. 786-793.

Cyro/Temp Therapy Systems; Product News Catalogue; Jobst Institute, Inc., 6 pages.

Copenheaver, Blaine R., International Search Report for PCT/US2007/022148 as mailed Apr. 2, 2008, 2 pages.

* cited by examiner

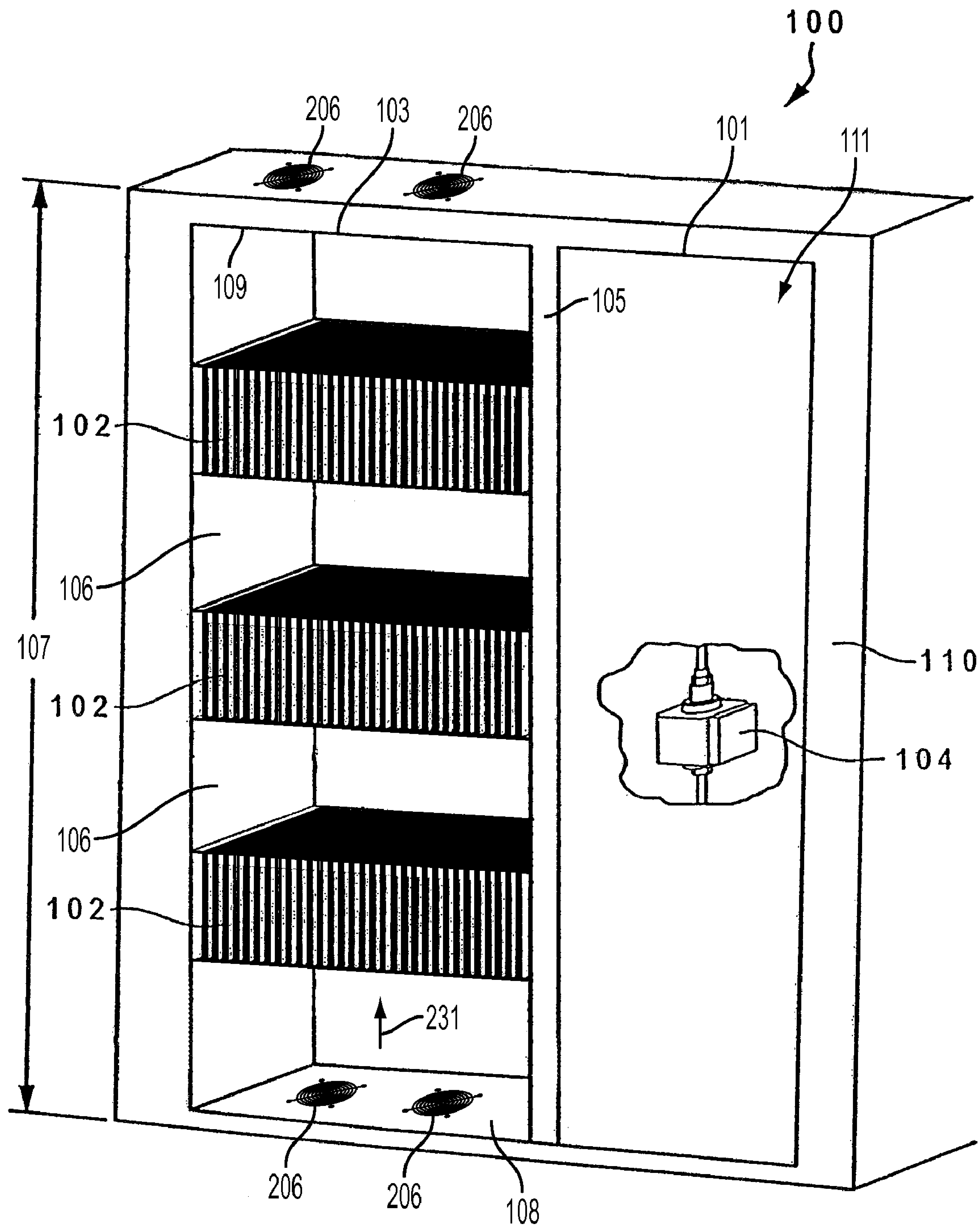


FIG. 1

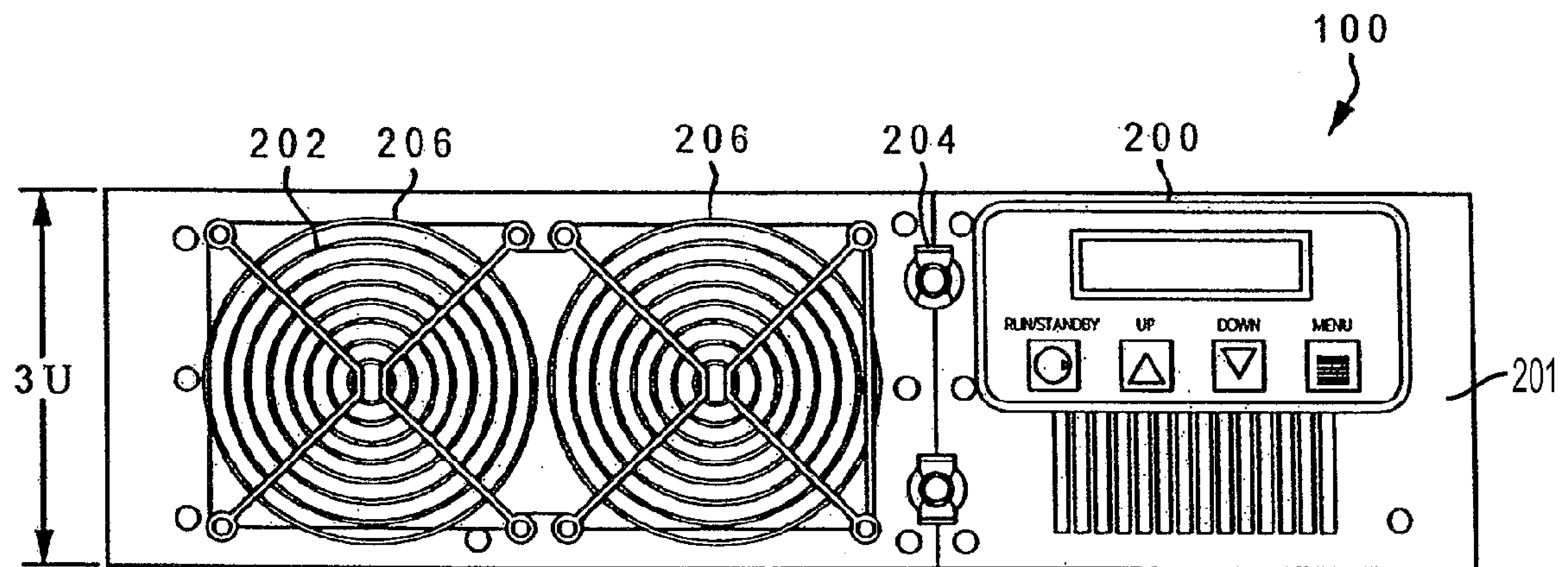


FIG. 2

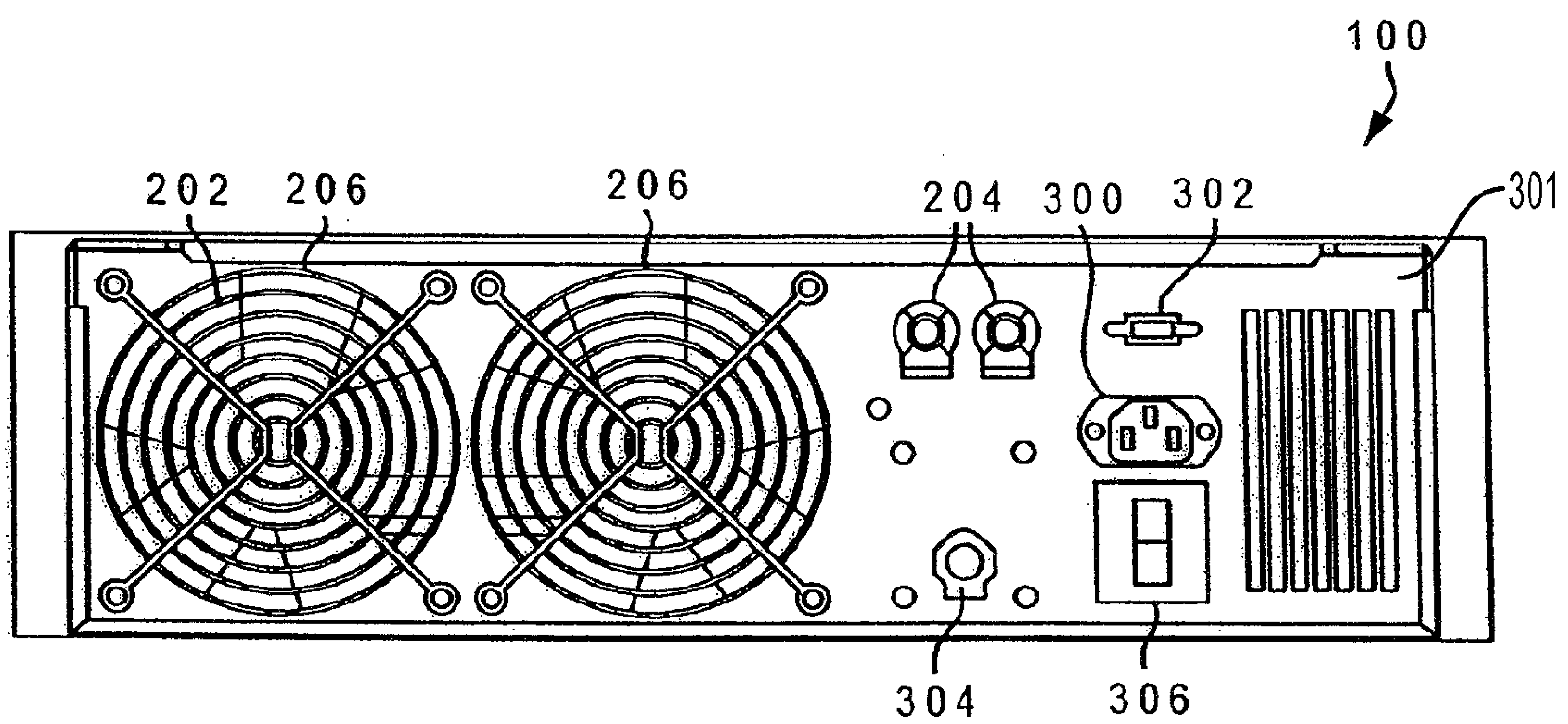


FIG. 3

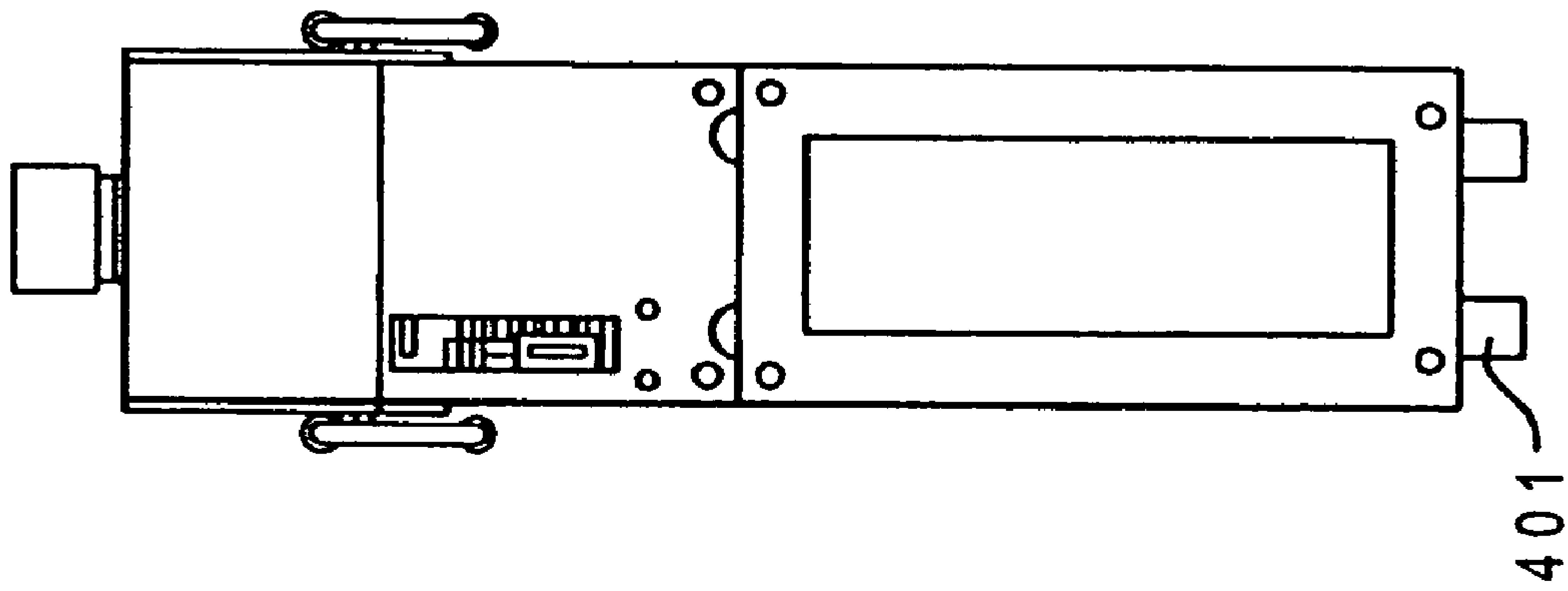


Fig. 4B

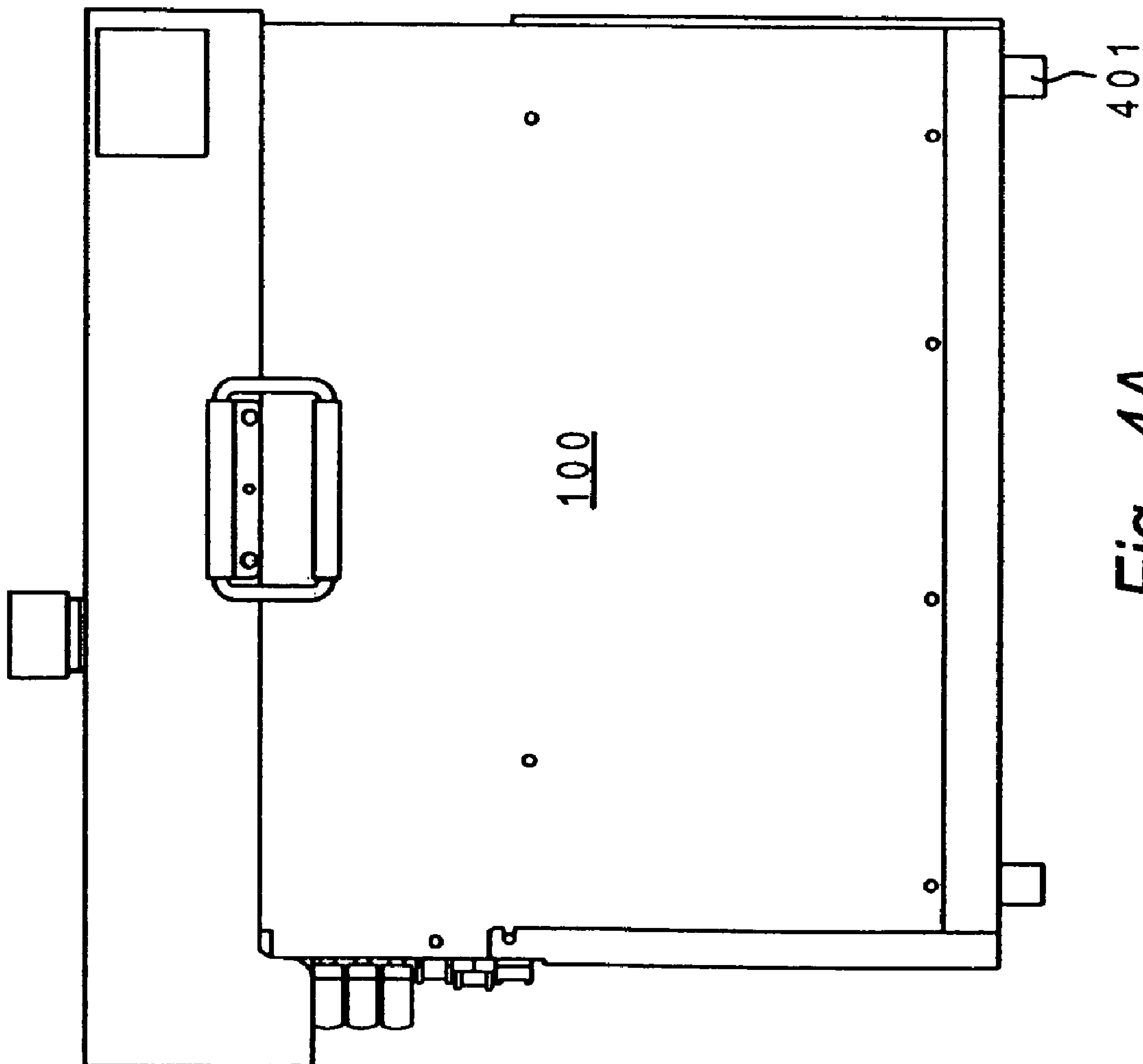


Fig. 4A

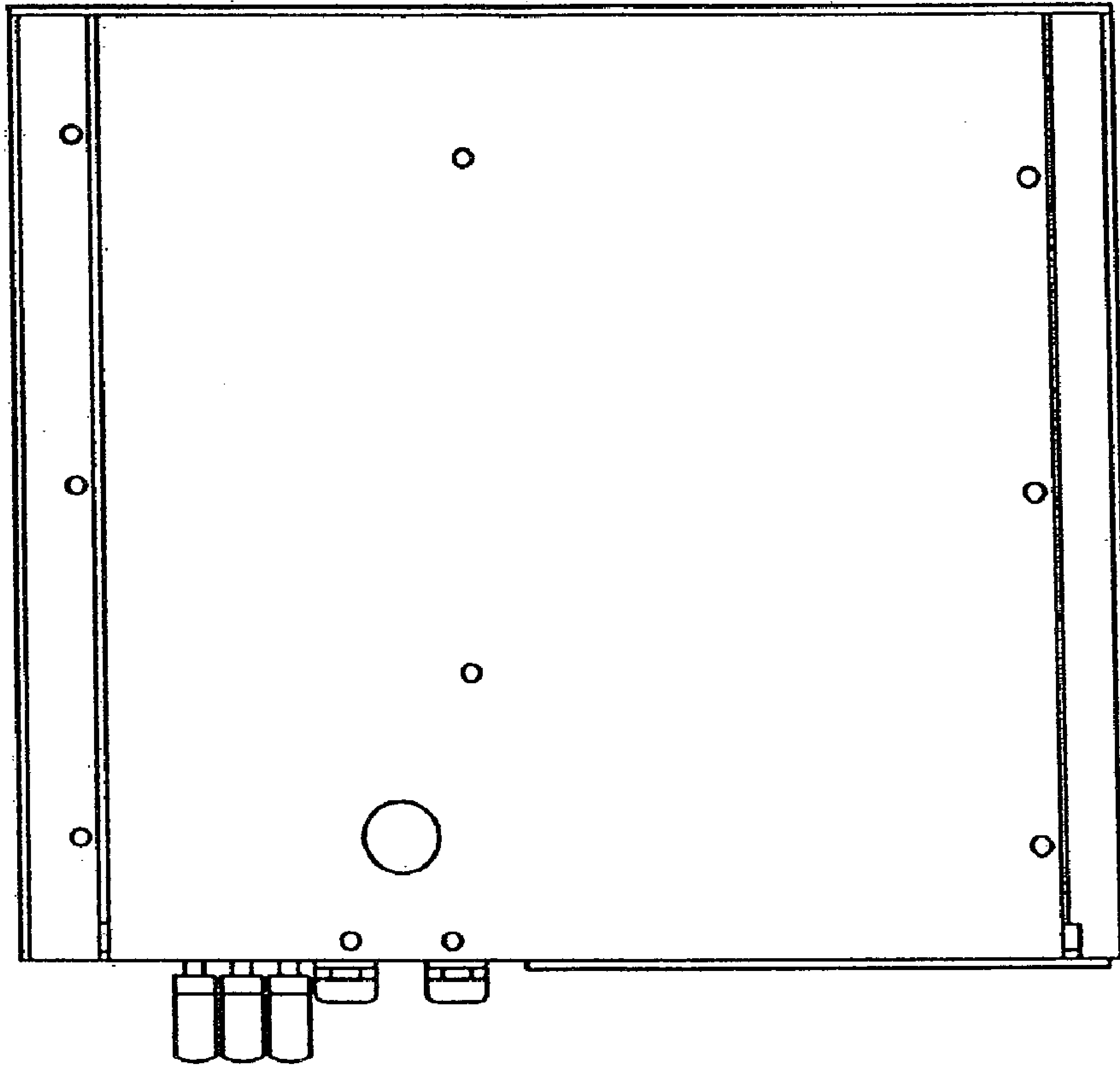


FIG. 5B

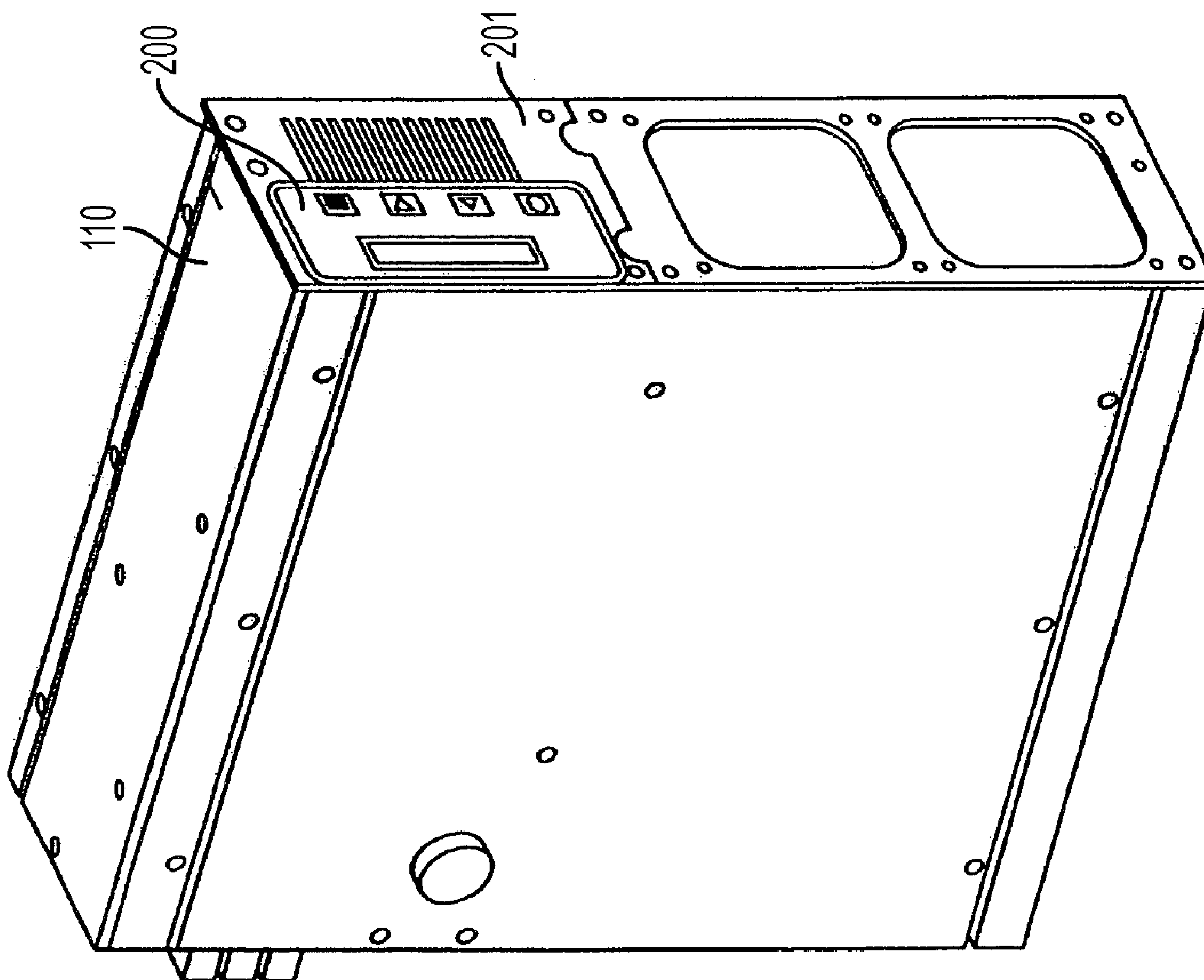


FIG. 5A

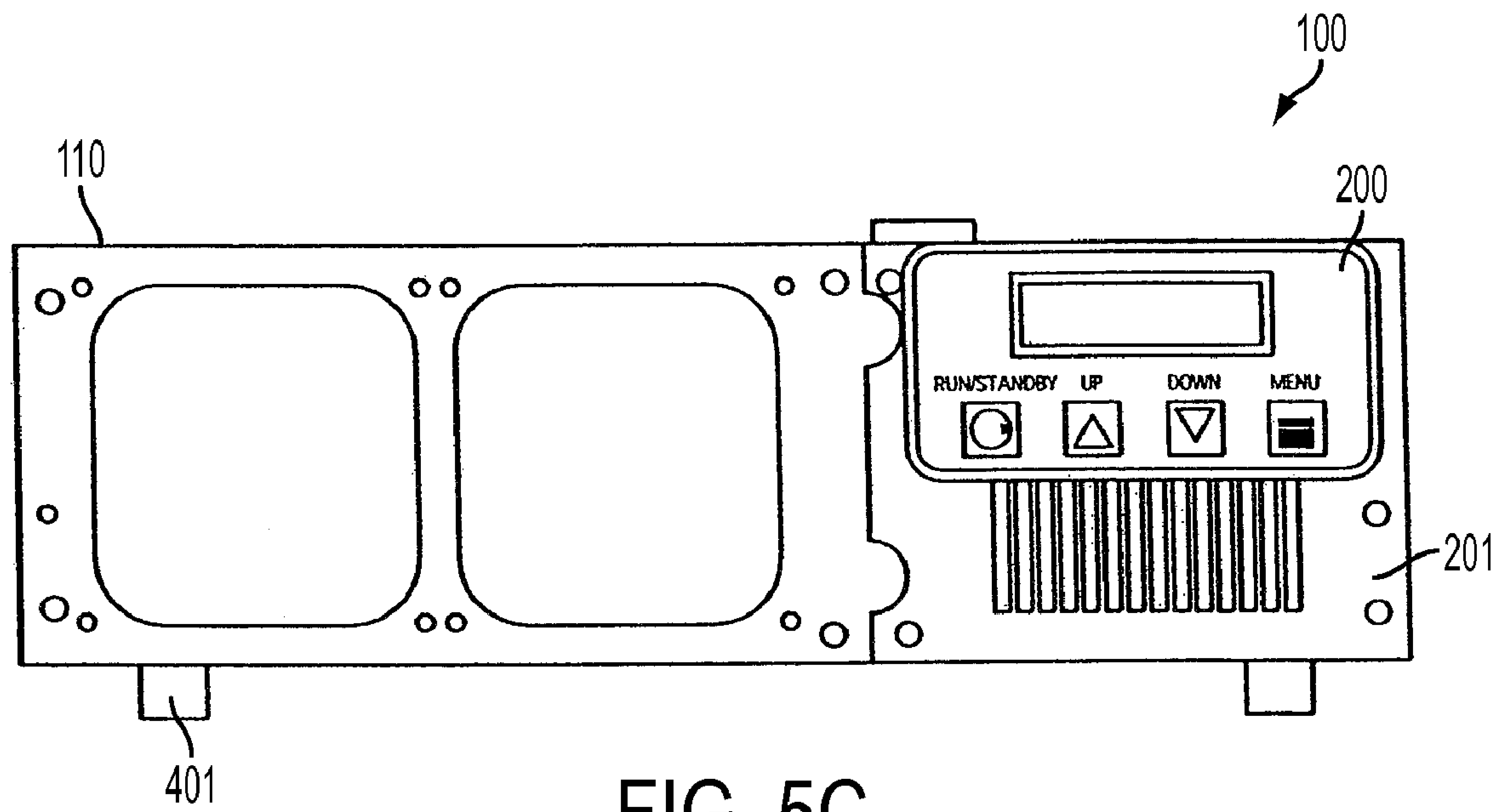


FIG. 5C

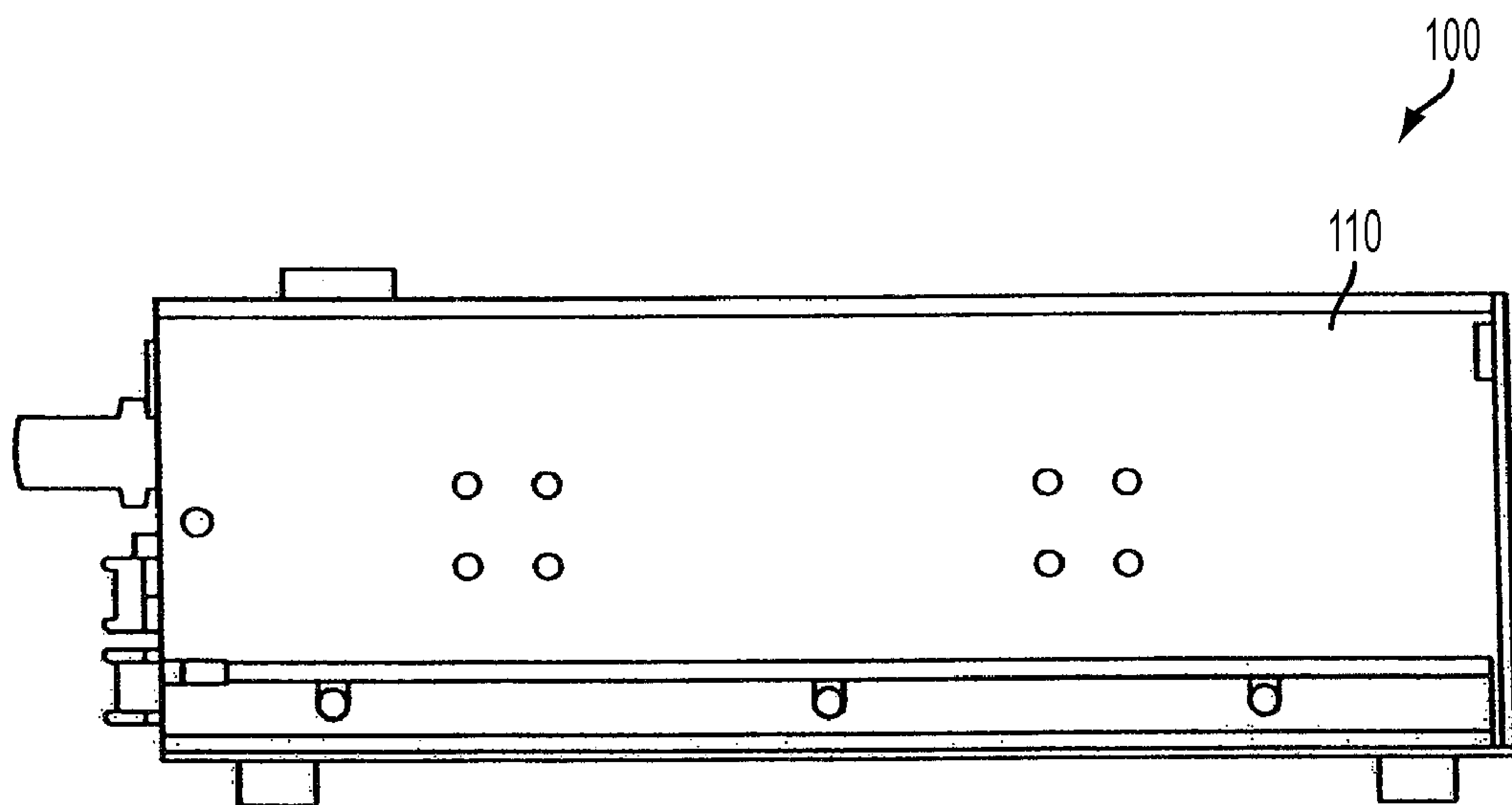


FIG. 5D

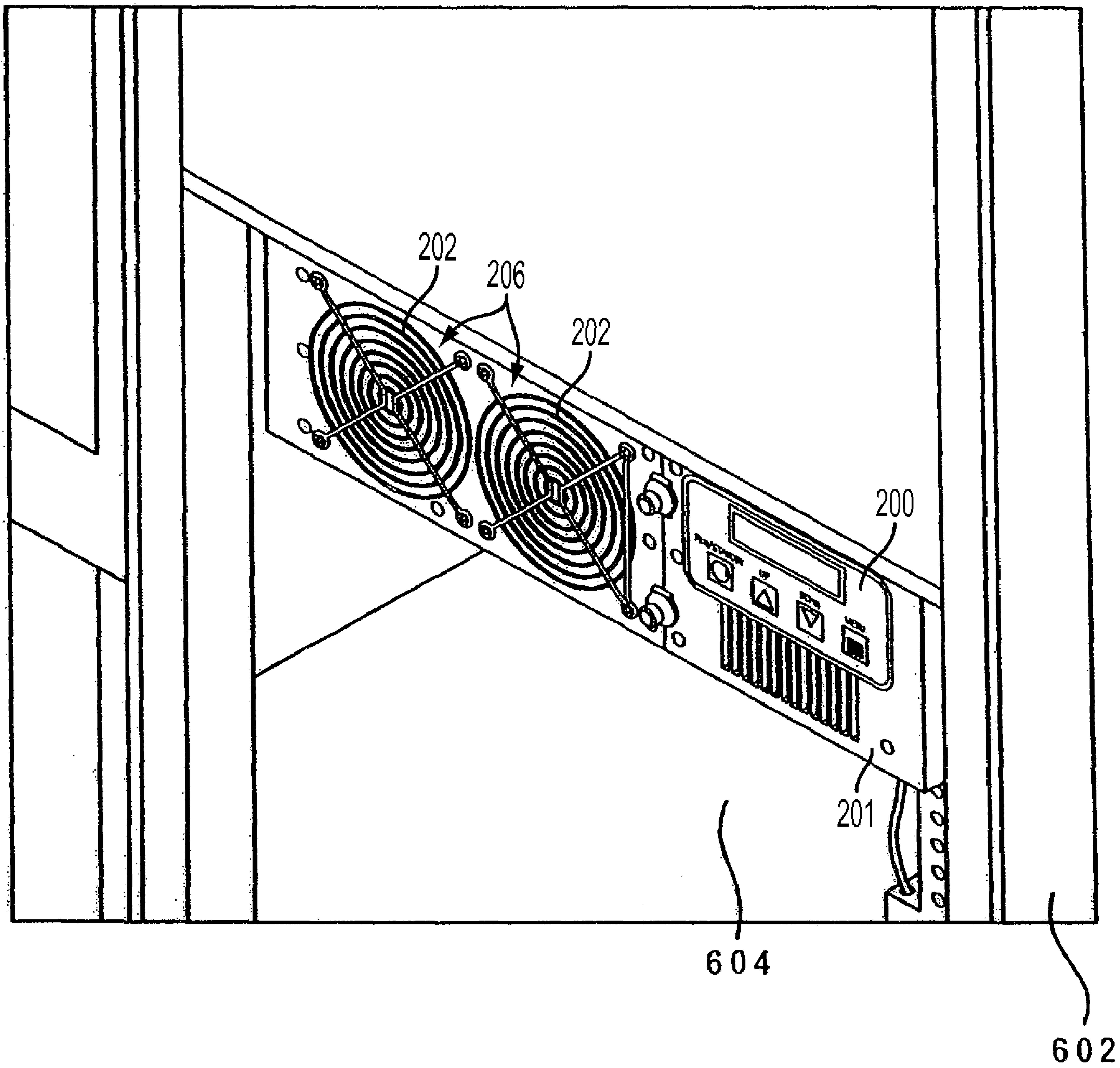


FIG. 6

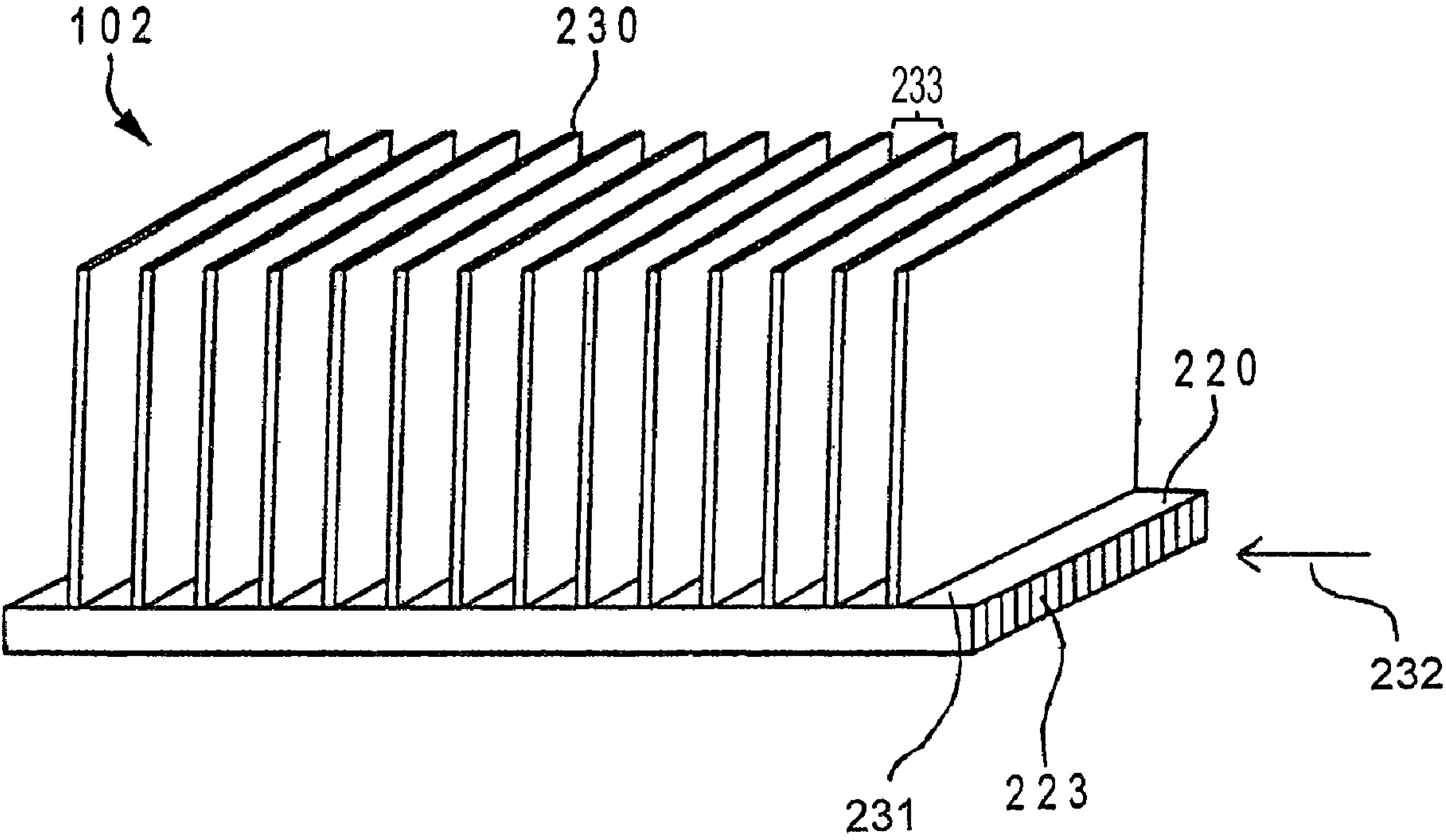


FIG. 7

Figure 8

SPECIFICATION:

1.	Heat Load (Watts):	0	100	200	500	1000	Other: ________
2.	Process Medium:	☐ 15% Glycol / 85% H_20 ☐ 15% Isopropyl Alcohol / 85% H_20 ☐ Distilled H_20 ☐ De-Ionized H_20					
3.	Process Set Temperature (°C):	-10	0	10	15	20	Other: ________
4.	Process Desired Flow (L):	0.5	1	2	3	4	Other: ________
5.	Estimated ΔP at Desired Flow (bar):	0.1	.25	1	2	4	Other: ________
6.	Total Hose Length (m):	0.5	1	2	4	8	Other: ________
7.	Hose Inside Diameter (mm):	3	4	5	6	8	Other: ________
8.	Hose Insulation	☐ Yes [STD]				☐ None	
9.	Hose Insulation Thickness (mm):	3	4	5	6	8	Other: ________
10.	External Process Filter:	☐ None [STD]				☐ External 25 μm Filter	
11.	Process Temperature Sensor:	☐ Internal [STD]				☐ External Sensor	
12.	Process Flow Measurement:	☐ None [STD]				☐ Flow Sensor	
13.	Process Conductivity Measurement:	☐ None [STD]				☐ DI Sensor	
14.	Cooling Medium:	☐ Ambient Air [STD]				☐ Plant Water	
15.	Design Ambient Temperature (°C):	10	15	20	25	30	Other: ________
16.	Cooling Medium Temperature (°C):	N/A	10	15	20	25	Other: ________
17.	Air Flow Configuration:	☐ Front to Back [STD]				☐ Side to Back	
18.	Air Filter:	☐ Included [STD]				☐ None	
19.	Input Voltage:	☐ 110 VAC ☐ 220 VAC / 60 Hz ☐ 220 VAC / 50 Hz ☐ Universal Input					
20.	Thermal Cycle Capability:	☐ 4,000 Cycles [STD]				☐ 40,000 Cycles	
21.	Interface:	☐ RS-232 [STD] ☐ RS-485 ☐ Ethernet					
22.	Coolant Pump Configuration:	☐ Centrifugal, 0.75 Bar, 3.0 LPM, 25K hours MTBF [STD] ☐ Positive Displacement, 4 Bar, 4.0 LPM, 10Khours MTBF ☐ Customer Supplied External Pump					
23.	Fan Configuration:	☐ Standard Fan [Low dB]				☐ High Performance Fan	
24.	External Fan Tray:	☐ None [STD]				☐ Fan Tray Module	
25.	Rack Depth	☐ 588 mm [23" STD]				☐ 381 mm [15"]	

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THERMAL CONTROL SYSTEM FOR RACK MOUNTING

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation of and incorporates by reference the entire disclosure of U.S. patent application Ser. No. 11/202,885, filed on Aug. 12, 2005 now abandoned. U.S. patent application Ser. No. 11/202,885 claims priority to U.S. Provisional Patent Application No. 60/601,013, filed Aug. 12, 2004, and incorporates by reference for all purposes the entire disclosures of U.S. patent application Ser. No. 09/328,183, now U.S. Pat. No. 6,935,409 filed Jun. 8, 1999 and U.S. Pat. No. 6,462,949, entitled "Electronic Enclosure Cooling System." This patent application incorporates by reference each of U.S. Provisional Patent Application No. 60/601,013, U.S. patent application Ser. No. 09/328,183, and U.S. Pat. No. 6,462,949.

BACKGROUND

1. Technical Field

The present invention relates to thermal control systems, and more particularly, but not by way of limitation, to low profile, rack mounted thermal control systems for cooling or heating equipment disposed in or in the vicinity of an equipment rack.

2. Background of Related Art

As the evolution of computers continued from mini-computers that filled entire rooms with equipment to PC modules similar to the personal computer known today, rack mounted equipment decreased in popularity. However, with the introduction of new electronic equipment, such as slice servers and laser systems, racks are returning to the computing environment. Rack mount enclosures are compact in design and allow for mounting of various components (e.g., servers, laser systems, chillers, etc.) in a stacked style configuration. Utilizing racks allows a user to include various rack mounted components in the rack, decreasing the foot print, while the components remain easily accessible for maintenance.

By mounting multiple components in a rack heat is increased, thereby causing deterioration and possible failure of many of the components. For example, most laser systems, such as those utilized for medical or industrial applications, generate a large amount of heat that requires cooling, via a chiller, in order to maintain proper function. In addition, many components, such as laser systems, perform poorly when subject to vibration and noise that many compressor-based chillers exhibit.

Conventional racks for the components as described herein are typically constructed of predetermined spatial parameters. For example, the height of an individual rack area, or "mounting space" adapted for conventional electronic components and the like is referred to in multiples of "U". Each "U" (standing for the word "unit") is equal to 1.75 inches. A 3U height is therefore 5.25 inches. It is this "U" height that defines the standard rack mounting spatial relationship relative to a typical "19" inch wide mounting space. The "19" inch reference refers in actuality to the space allotted outside the mounting spaces for the equipment or component face plate. The inside of the mounting space generally has an inside dimension on the order of 17.5 inches. Using these spacing parameters, components and equipment mounted within such a rack are typically of a height that is a "U" multiple with a face panel on the order of 19 inches wide.

Although many components, such as servers and laser systems, are available in a height that is on the order of a "U" multiple for placement in the conventional rack, rack mounted chillers typically require a height of more than 3U to offer effective cooling to the surrounding components. Some compressor-based units may require as much as an 8U height. It should be noted, however, that such height is critical to space considerations of the overall rack. Conventional equipment racks only have a specified number of U's available and the higher the number of U's required for temperature control equipment, the fewer U's available for the necessary equipment. It is for this reason that special height considerations are important along with the functionality of the temperature control system.

Today's cooling technology typically includes passive cooling systems, compressor-based systems, and thermoelectric systems. In certain passive cooling systems, the air to be cooled is circulated over an air-to-air heat exchanger, which includes folded, finned heat exchangers, heat pipes, etc. The heat is then exchanged with the outside ambient air. As the amount of heat to be removed from the area increases, the size of the air-to-air heat exchanger increases. Compressor-based systems function by using a refrigerant and the cooling function is achieved by the compression and expansion of the refrigerant such as European Patent Application 1488040A2, entitled "Liquid Cooling System for a Rack-mount Server System," which is hereby incorporated by reference. These compressor-based systems typically weigh over seventy pounds and create unwanted vibrations. Thermoelectric temperature control systems use thermoelectric devices that pump heat using the Peltier effect. Typical thermoelectric devices incorporate a thermoelectric component that utilizes electrical current to absorb heat from one side of the component and dissipate that heat on the opposite side.

In addition to the above, instances arise where heating and/or temperature stabilization is equally important. For example, laser systems require a stable heat and temperature environment because the frequency of the light is dependent on the temperature of the diode. When rack-mounted systems that are vibrationally sensitive require precise temperature control, a compressor based system cannot be used. Thus, a more technologically complex scenario can evolve. A simple chiller is generally not capable of also performing a heating function without adding resistive elements. Thermal electric temperature control systems using thermal electric devices are, as described above, capable of both heating and cooling, low vibration, relatively high Coefficient Of Performance ("COP's") (ability to remove heat), low noise, and low profile.

U.S. patent application Ser. No. 09/328,183 (the '183 patent application), now U.S. Pat. No. 6,935,409, assigned to the assignee of the present invention teaches a heating and cooling system with low vibration, relative high COP's, low noise and low profile. The low profile cooling system of the '183 patent application is, as stated therein, particularly well suited for cooling power amplifiers and other electronic components. In one embodiment, a heat transfer fluid is circulated in a closed loop to the area of components that generate heat. This approach allows the design, implementation and utilization of such thermoelectric cooling systems utilizing low profile extrusions capable of cooling high watt density sub assemblies such as a power amplifiers and filters commonly secured in rack mounted equipment or equipment that may be mounted around a conventional electronic component rack.

It would therefore be a distinct advantage relative to the above-described technology to provide a thermal control sys-

tem that would be of low vibration, high efficiency, and yet easily mountable within a conventional rack with minimal "U" utilization.

SUMMARY

The present invention relates to thermal control systems for equipment. More particularly, one aspect of the invention relates to low profile, rack-mounted temperature control systems for cooling or heating equipment disposed in or in the vicinity of an equipment rack. The control system is constructed in a 3U (3×1.75"=5.25 inches) height for placement in standard "19" inch wide equipment rack units (inside dimension of unit is in the order of 17½ inches.

In another aspect, the present invention relates to a thermal control system including at least one Heat Transfer Assembly (HTA) module. The HTA modules are formed of low profile extrusions having micro channels formed therein. The HTA's may include external fins and/or high density bonded fin heat sinks.

In another aspect, one embodiment of the invention includes a thermal control system for heating and cooling select equipment disposed in the vicinity of conventional 19 inch equipment racks having an interval mounting space width on the order of 17.5 inches for the placement of equipment therein, and a height on the order of 3U. The system further includes at least one heat transfer assembly module of the type formed with a plurality of low profile extrusions having micro channels formed therein and disposed within a chassis for the flow of heat transfer fluid for thermal control and a height no more than 3U.

In another aspect, the above-described embodiment includes the heat transfer fluid being circulated in a closed loop to cool or heat components within the rack wherein the thermal control system is disposed. In one embodiment, the heat transfer fluid includes a water/glycol mixture, and in another embodiment it includes a water/alcohol mixture.

In yet another embodiment, the above-described invention includes the ability to customize the design of the 3U system and allow on the order of three heat transfer assemblies to effect cooling and/or heating of the temperature control system. A plurality of internal fan assemblies may also be further utilized in conjunction with the heat transfer fluid for the effective transfer of heat therefrom.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method and apparatus of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

FIG. **1** is a top view of a temperature control system in accordance with an embodiment of the present invention.

FIG. **2** is a front view of a temperature control system in accordance with an embodiment of the present invention.

FIG. **3** is a back view of a temperature control system in accordance with an embodiment of the present invention.

FIG. **4**A is a side-elevation view of the temperature control system with rubber feet attached for standing in a vertical position.

FIG. **4**B is a front elevation view of the temperature control system with rubber feet attached for standing in a vertical position.

FIG. **5**A is a perspective view of the temperature control system with rubber feet attached for standing in a horizontal position.

FIG. **5**B is a bottom view of the temperature control system with rubber feet attached for standing in a horizontal position.

FIG. **5**C is a side elevation view of the temperature control system with rubber feet attached for standing in a horizontal position.

FIG. **5**D is a front elevation view of the temperature control system with rubber feet attached for standing in a horizontal position.

FIG. **6** shows the temperature control system as it would fit into a conventional rack mount.

FIG. **7** is a perspective view of an HTA module of the type used in FIG. **1**.

FIG. **8** is a table detailing various elements that can be selected by the customer to be included in the chassis of the temperature control system of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS OF THE INVENTION

Referring now to FIG. **1**, a top view of a temperature control system **100** in accordance with an embodiment of the present invention is illustrated. The temperature control system **100** utilizes a heat transfer fluid that is circulated in a closed loop to cool or heat components within a conventional rack. The heat transfer fluid may be, for example, a water/glycol mixture, although other heat transfer fluids may be utilized. In one embodiment, the temperature control system **100** is contained in a chassis **110** having an available internal space **111**, a front face **201** and, a rear face **301**. In one embodiment, three HTA modules **102** are utilized to effect cooling and/or heating in the temperature control system **100**, however embodiments of the present invention may include more or fewer HTA modules as desired. As clearly illustrated in FIG. **1**, the HTA modules **102** are secured in a chassis **110** in a continuous heat transfer chassis region **103**. Spaces **106** are disposed between adjacent HTA modules **102**. The HTA modules **102** are oriented parallel to each other and perpendicular to a depth **107** of the chassis **110**. The continuous heat transfer chassis region **103** occupies over half of the available internal space **111** of the chassis **110**. The temperature control system **100** may also include up to six internal fan assemblies (not shown) and an addition three internal fans with an external fan tray. The fans may be oriented in a push/pull fan arrangement or other arrangement as desired. In alternate embodiments, fans on the heat transfer side are not included. Instead, the temperature control system **100** may utilize micro extrusions to transfer power from the Thermoelectric Cooling Module ("TEC") via water. The power supplies that drive the TEC's may have variable output (5-135 Vdc) which can be varied by the controller using, for example, a Pulse Width Modulation ("PWM") signal. This variable output design of the power supply can modulate the power to the TEC's to achieve precise temperature control. This variable output also allows the chiller to only use the minimum required input power to provide the optimal control. This lowers the overall input power required by lowering the drive voltage to the TEC's in applications that have low heat loads. A preferred embodiment of the present inventions has thermal performance capabilities of 725 Watts at 0° C. delta T supply minus ambient air. An alternative embodiment of the present inventions utilizing a plant water supply has capabilities in excess of 1,100 Watts at 0° C. delta T supply minus service water.

The fan assembly **206** maximizes efficiency of the temperature control system **100** by maximizing the airflow (denoted by arrow **231**) to the HTA modules **102**. In one embodiment, shown in FIG. **7**, the HTA modules **102** of the present

invention are formed of low profile extrusions **220** having a plurality of micro channels **223**. Each micro channel **223** has a micro channel inlet and a micro channel outlet. The low profile extrusions **220** preferably formed with heat sinks **231** and external fins **230** to maximize heat transfer, if space allows. The fins **230** are constructed having spaces **233** disposed there between. In a typical embodiment, the HTA modules are arranged so that the spaces **233** are parallel to a depth **107** of the chassis **110**. The micro channel inlets are in fluid communication with each other, and to an inlet channel, by an inlet end cap. Similarly, micro channel outlets are in fluid communication with each other, and to the outlet channel, by an outlet end cap. The heat transfer fluid (denoted by arrow **232**) is circulated through the inlet channel, the low profile extrusion **220**, the outlet channel, and tubing via the pump **104**. As shown in FIG. **1**, in a typical embodiment, the heat transfer fluid **232** flows through the low profile extrusion **220** in a direction perpendicular to the depth **107** of the chassis **110**. The pump **104** is disposed within the chassis **110** in a continuous pump region **101**. The continuous pump region **101** occupies less than half of the available internal space **111** of the chassis **110** and is disposed adjacent to the continuous heat transfer chassis region **103**. The continuous pump region **101** and the continuous heat transfer region **103** are separated by a boundary **105**. The boundary **105** is disposed parallel to the depth **107** of the chassis **110** and runs between an interior aspect **108** of the front face **201** to an interior aspect **109** of the rear face **301**. Alternatively, the temperature control system **100** may be evacuated and charged with fluid which is then circulated via the pump **104**. Further details regarding low profile extrusions **220** and the heat transfer fluid flow system and method herein referenced are set forth and shown in U.S. patent application Ser. No. 09/328,183, now U.S. Pat. No. 6,935,409, referenced above and incorporated herein by reference.

The temperature control system **100** utilizes a pump **104**, such as a positive displacement, centrifugal, or turbine style magnetically coupled pump. The pump **104** is of such a size as to fit in the 3U configuration and may have a variety of gear sizes, port sizes, etc. as needed. The customized selection of the pump and other components may also be provided in the 3U system as described below. A preferred embodiment of the present invention has flow rate capabilities on the order of one gallon per minute or four Liters per minute.

The temperature control system **100** is formed in a modular design to allow flexibility and versatile configuration for a variety of customers. For example, a customer may request one or two HTAs with a smaller displacement pump in order to create a chiller with less depth, allowing the chassis to only be fifteen inches in depth compared to the standard twenty three inches. In addition, the present invention also may have high thermal cycle module capability. A preferred embodiment of the present invention has the capability of remote temperature monitoring utilizing external temperature sensors such as thermistors or Resistance Temperature Detection ("RTD") devices, etc. A preferred embodiment of the present invention also allows user communication in a variety of manners including serial USB ports, Ethernet ports, RS485 ports and RS232, etc. The present invention has the capability of operation off a DC power source (150-340 Vdc) or universal AC voltage operation (95-250 Vac, 45-70 Hz). There are various wiring selections that can be utilized to maximize the efficiency of the system based on the input voltage. Conductivity meters and voltage sensors may also be utilized to ensure the accuracy of the system. Another preferred embodiment of the present invention utilizes flow meters to monitor air flow across the HTA's and the fluid flow of the heat transfer fluid. The fluid in the present invention can utilize various fluid connections and types depending on the specific needs of the user. One contemplated embodiment utilizes the present invention in conjunction with both external heat exchangers including air and plant liquid coolers. Utilizing the flow meters and conductivity meters in conjunction with the temperature sensors gives the thermal control system the capability of maintaining the temperature of the heat transfer fluid to within +/−0.05 degrees Celsius.

Another aspect of one embodiment of the present invention is the flexibility that the 3U design affords relative to the customer requests referred to above. As seen in FIG. **1**, the temperature control system **100** includes a chassis **110** that provides a basic frame for a variety of options that may be utilized therewith pursuant to customer specification while maintaining the 3U height limitation for rack mounting in accordance with the principles of the present invention. In addition to the 3U height limitation, the present invention weighs approximately fifty-four pounds, making it suitable for a variety of applications. FIG. **8** is thus submitted for illustrating the high level of specificity with which a customer may select various elements within the temperature control system **100** and securement to the chassis **110**. By utilizing the chart shown in FIG. **8**, the manufacturer of the present invention is able to utilize an "assembly line" type of fabrication without the need for multiple redesign and re-engineering to meet the 3U and/or performance criteria. The various elements as set forth in the chart shown in FIG. **8** can be selected and will all fit within the chassis **110** and within the 3U module fitting into a 3U mounting space of the conventional rack, even though the temperature control system **100** has been customized by a given customer.

SPECIFICATION:

1.	Heat Load (Watts):	0	100	200	500	1000	Other: ______
2.	Process Medium:	☐ 15% Glycol / 85% H_2O ☐ 15% Isopropyl Alcohol / 85% H_2O ☐ Distilled H_2O ☐ De-Ionized H_2O					
3.	Process Set Temperature (°C):	-10	0	10	15	20	Other: ______
4.	Process Desired Flow (L):	0.5	1	2	3	4	Other: ______
5.	Estimated ΔP at Desired Flow (bar):	0.1	.25	1	2	4	Other: ______
6.	Total Hose Length (m):	0.5	1	2	4	8	Other: ______
7.	Hose Inside Diameter (mm):	3	4	5	6	8	Other: ______
8.	Hose Insulation	☐ Yes [STD]				☐ None	
9.	Hose Insulation Thickness (mm):	3	4	5	6	8	Other: ______
10.	External Process Filter:	☐ None [STD]				☐ External 25 μm Filter	
11.	Process Temperature Sensor:	☐ Internal [STD]				☐ External Sensor	
12.	Process Flow Measurement:	☐ None [STD]				☐ Flow Sensor	
13.	Process Conductivity Measurement:	☐ None [STD]				☐ DI Sensor	
14.	Cooling Medium:	☐ Ambient Air [STD]				☐ Plant Water	
15.	Design Ambient Temperature (°C):	10	15	20	25	30	Other: ______
16.	Cooling Medium Temperature (°C):	N/A	10	15	20	25	Other: ______
17.	Air Flow Configuration:	☐ Front to Back [STD]				☐ Side to Back	
18.	Air Filter:	☐ Included [STD]				☐ None	
19.	Input Voltage:	☐ 110 VAC ☐ 220 VAC / 60 Hz ☐ 220 VAC / 50 Hz ☐ Universal Input					
20.	Thermal Cycle Capability:	☐ 4,000 Cycles [STD]				☐ 40,000 Cycles	
21.	Interface:	☐ RS-232 [STD] ☐ RS-485 ☐ Ethernet					
22.	Coolant Pump Configuration:	☐ Centrifugal, 0.75 Bar, 3.0 LPM, 25K hours MTBF [STD] ☐ Positive Displacement, 4 Bar, 4.0 LPM, 10Khours MTBF ☐ Customer Supplied External Pump					
23.	Fan Configuration:	☐ Standard Fan [Low dB]				☐ High Performance Fan	
24.	External Fan Tray:	☐ None [STD]				☐ Fan Tray Module	
25.	Rack Depth	☐ 588 mm [23" STD]				☐ 381 mm [15"]	

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Referring now to FIG. **2**, a front view of the temperature control system **100** is illustrated. The temperature control system **100** exhibits a front to back air flow and easily removable air filter. The front panel of the temperature control system **100** includes a user interface **200**, such as a membrane keypad or other user interface. The user interface **200** allows the user to enter various information (e.g., set various conditions, adjust fan speed, adjust temperature, display flow, heat load, thermal performance, etc.) for use by the temperature control system **100**. At least one fan guard **202** protects the fan blades of the fan assemblies **206**. The front panel may also include fluid connections **204** including but not limited to quick Connections, National Pipe Taper ("NPT"), etc.

In operation, the 3U system of the present invention affords multiple advantages for both the customer and user. Thermal control systems utilizing a 3U height and manifesting low vibration consistent with the technology set forth and described herein is a distinct advantage. The ability to customize the particular operational system parameters within the temperature control system **100** is likewise of significant benefit. The system **100** can be upgraded as required while manifesting quiet operation, low vibration and being energy efficient even after upgrades. The upgrades are, as referenced above, integral elements that may be selected by the customer and therefore are all compatible with the remaining elements within the 3U system of the present invention.

Referring now to FIG. **3**, a rear panel of the temperature control system **100** is illustrated. The rear panel also includes fan guards **202** and fluid connections **204** similar to those of the front panel. Also oriented on the rear panel is a power entry module **300** for supplying power to the thermal control system **100**. A reservoir filler quick disconnect **304**, communication IP ports including alarms, stand by signals, expansion/accessories, electronics side vents, and an RS232 interface connection **302** are included on the rear panel as well. A circuit breaker **306** prevents the thermal control system **100** from being overloaded by a surge in power.

Referring now to FIGS. **4A** and **4B**, the thermal control system is shown with the face plate trimmed down and with feet added. This embodiment utilizes the advantages of the slim, low profile design, low vibration, and precise temperature control in a bench top vertical unit. An alternative embodiment of the bench top unit has feet **401** attached in such a way so that the face plate is oriented in the same direction as when mounted in a rack giving a bench top horizontal unit. These configurations keep the unit stable even when not mounted in a conventional rack, allowing it to be used for a plurality of purposes.

Referring now to FIGS. **5A-5D** and FIG. **6**, the thermal control system is shown disposed in a conventional rack mount **602**. The 3U height of the chassis allows it to fit in the slots **604** of the conventional rack mount **602**, taking up no more space than most standard electronic equipment. The design of the chassis also allows the thermal control system to be secured to the conventional rack mount **602** in number of different ways, one being with screws through the faceplate.

There are several modifications and variations of the innovative concepts of the present application that are contemplated and within the scope of the patented subject matter. A few examples of these alternative embodiments are given below, but in no way do these examples enumerate all possible contemplated embodiments of the present application.

For example, one contemplated embodiment of the present invention utilizes two temperature control systems for increased cooling capabilities. The present invention has the capability of being connected in a Master/Slave type relationship where both temperature control systems have the capability of being mounted in two separate mounting spaces of a conventional mounting rack.

An example of an alternative embodiment includes mounting the thermal control system independent of the conventional mounting rack. Rubber feet may be added and the system can be placed on a desktop.

Another alternative implementation that is contemplated would be to use the thermal control system disclosed in the present application in conjunction with an external heat exchanger. In this embodiment, the thermal control system would cool the air that passes over the micro channels and at the same time warm the heat transfer fluid. The heat transfer fluid could then be cooled by some external heat exchanger, e.g. plant water. This embodiment may be desirable to use in a closed environment such as a clean room, where the only air exchange possible is through recirculation.

Another example embodiment includes using the thermal control system for the temperature regulation of vehicle parts or compartments in a vehicle.

The previous description is of a preferred embodiment for implementing the invention, and the scope of the invention should not necessarily be limited by this description. The scope of the present invention is instead defined by the following claims.

What is claimed is:

1. A precision thermal control system comprising:

a chassis having an available internal space and a height of no more than 3U, the chassis comprising:

a front face;

a rear face;

a continuous heat transfer chassis region occupying over half of the available internal space of the chassis, the continuous heat transfer chassis region not being coextensive with the available internal space of the chassis, the continuous heat transfer chassis region extending from an interior aspect of the front face to an interior aspect of the rear face; and

a continuous pump region comprising a pump, the continuous pump region occupying less than half of the available internal space of the chassis, the continuous pump region extending from the interior aspect of the front face to the interior aspect of the rear face, the continuous pump region and the continuous heat transfer region positioned adjacent to each other along a boundary oriented parallel to a depth of the chassis;

a first plurality of fan assemblies disposed adjacent to the front face, the first plurality of fan assemblies connecting the continuous heat transfer chassis region with an exterior environment;

a second plurality of fan assemblies disposed adjacent to the rear face, the second plurality of fan assemblies connecting the continuous heat transfer chassis region with the exterior environment, the first and second plurality of fan assemblies operable to allow an airflow through the continuous heat transfer chassis region;

a user interface disposed on a portion of the front face corresponding to the continuous pump region;

a first plurality of fluid connections disposed on a portion of the front face corresponding to the boundary;

a second plurality of fluid connections disposed on a portion of the rear face corresponding to the boundary;

wherein the continuous heat transfer chassis region comprises:

a plurality of heat transfer assembly modules secured to the chassis within the heat transfer chassis region, the

plurality of heat transfer assembly modules oriented parallel to each other and perpendicular to the depth of the chassis; and

a plurality of spaces disposed between each of the heat transfer assembly modules disposed within the heat transfer chassis region,

wherein, each of the plurality of heat transfer assembly modules disposed within the heat transfer chassis region comprises:

a low profile extrusion having micro channels formed therein;

a heat transfer fluid disposed within the low profile extrusion; and

a plurality of external fins disposed on the low profile extrusion, the plurality of fins having a plurality of gaps therebetween, the plurality of gaps oriented parallel to the depth of the chassis;

wherein the airflow through the continuous heat transfer chassis region is parallel to the depth of the chassis; and

wherein the flow of the heat transfer fluid through the low profile extrusion is perpendicular to the depth of the chassis.

2. The system as set forth in claim **1** comprising three heat transfer assembly modules utilized to effect cooling and/or heating in said precision thermal control system.

3. The system as set forth in claim **1** wherein said precision thermal control system is portable.

4. The system as set forth in claim **3** wherein said precision thermal control system further comprises a plurality of support feet adapted to be secured along at least one surface of said chassis for facilitating the placement of said precision thermal control system outside of a conventional equipment rack.

5. The system as set forth in claim **1** wherein said precision thermal control system is programmable.

6. The system as set forth in claim **5** wherein a user sets a range of satisfactory temperatures of said heat transfer fluid and said precision thermal control system automatically adjusts a fan speed and a flow rate of said heat transfer fluid in at least partial dependence on said range of satisfactory temperatures.

7. The system as set forth in claim **5** wherein said precision thermal control system records information the temperature of said heat transfer fluid.

8. The system as set forth in claim **7** wherein the information recorded by said precision thermal control system can be displayed or printed.

9. The system of claim **1** further comprises a variable-output power supply secured within the chassis, wherein an output of the variable-output power supply is varied by a controller via a pulse width modulation signal.

10. The system of claim **1** further comprises a variable-output power supply secured within the chassis, wherein the variable-output power supply allows the precision thermal control system to use a minimum required input power to provide thermal control.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

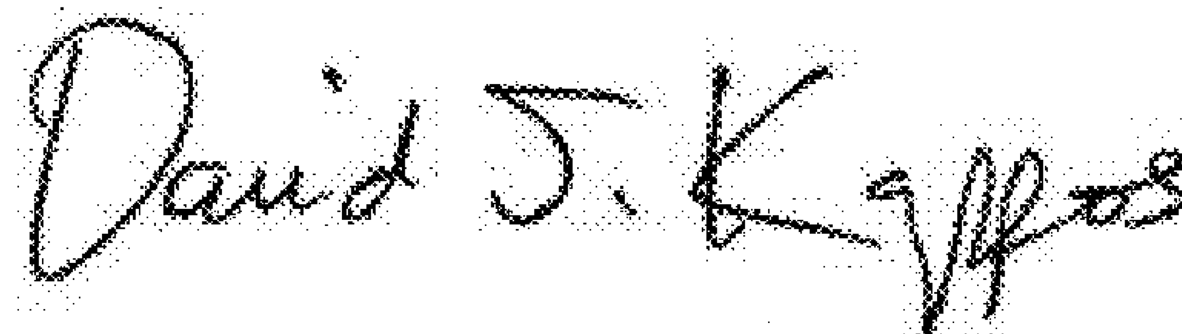
CERTIFICATE OF CORRECTION

PATENT NO. : 7,804,686 B2
APPLICATION NO. : 12/176084
DATED : September 28, 2010
INVENTOR(S) : Overton L. Parish et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title Page, Item (56)
In the Cited References, Other References
Insert --Young, Lee W., “International Search Report” for PCT/US07/08807 as mailed March 3, 2008, (3 pages).--

Signed and Sealed this
Fifteenth Day of February, 2011



David J. Kappos
Director of the United States Patent and Trademark Office